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GLACIERS AND SEA ICE EXTENT IN ICELAND DURING THE QUATERNARY

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In Iceland glacier development is closely related with the extent of the sea ice and the inland precipitation mostly controlled by the Irminger Current, a branch of the North Atlantic mild Current. Also the relief inherited from the volcanic activity of the hotspot favours the formation of the ice sheet, together with the cooling brought by the Eastern Cold Current derived from the Eastern Greenland current. This is the reason of the formation of an ice sheet in the South-East of the island where precipitation and the relief are the highest. The North is usually arid, a limiting factor for the glacial extent. During thermal optimum, glaciers usually vanish but restore during cooling events, especially late interglacials: it never reached a permanent volume as the Greenland or Antarctica ice sheets. Sea ice is for the moment absent, but developed along the Northern coast during the Little Ice Age. Sea ice extent prevent sea water vaporization and thus snow accumulation on land. Moreover, because of its position in the central northern Atlantic, Iceland is an intergrade between Greenland and the Eastern America, cooled by the Eastern Greeland Current and Scandinavia, warmed and sprayed thanks to the mild North Atlantic drift during interglacials.

Curiously, the Pleistocene stratigraphy of Iceland is very limited even about 20 glaciations are recorded for the whole Quaternary. Well constrain for the Plio-Pleistocene, almost no clear stratigraphy is given for the Quaternary, excepted since the Older Dryas (13-12ka) and the Last Deglaciation. A lot of controversies exist, easy by limited dating, especially for the Middle and Upper Pleistocene. K-Ar dating and detailed stratigraphical work has raised the possibility of a more detailed record, especially for the Middel and Upper Pleistocene, more in conformity with marine records around the island and in other Nordic countries than the favourite interpretations.

The first glaciations in Arctic.

Since 14 Ma, IRD in marine cores from the Northern Atlantic evidence the drift of icebergs on the Northern Atlantic (Bleil, 1989). Earlier events are speculative, only located on the eastern margins of Greenland, where glaciations are well recorded from 7 Ma (Larsen et al, 1994; Solheim et al., 1997); earlier events can be derived from local glaciers or even sea ice. Platform and inland evidences of glaciations are much younger, usually recorded from the Middle Pliocene (3.3 ma), as on the Barents Shelf, when the Bering Strait opened. The Yakataga glacio-marine Formation in the Gulf of Alaska was first interpreted as early Miocene (c.20 Ma), but now relocated into the Pliocene, even mountain glaciers were probably pre-existing in altitude since 38 Ma. A glacial intensification in the circum-Atlantic region occurred from c2.7 Ma (Jansen et al., 2000; Kleiven et al., 2002; Haug et al, 2005, Bartoli et al., 2006), with a distinct supply of IRD-rich sediments on the Yermak Plateau between c. 2.7 and 2.4 Ma .

The very first glaciations in Iceland.

The age of the Tertiary basalt formation ranges from 16 Ma. Iceland is thus a very good place to analyse the occurrence of early glaciations. Observations by Geirsdottir and Eiriksson (1994, Geirsdottir , 2004; Geirsdottir et al. 2007) have shown that the onset of glaciations in the North and in the East also give a similar answer as in most Arctic. Fossil fauna in sedimentary beds interlayered with basaltic floods attest of a progressive cooling from subtropical close to 16 Ma to temperate at 7 Ma. Glaciers have been developing in the southeast since the late Miocene (c. 9 Ma). Evidence of glaciers (tillites) are interbedded with basalts in the East (Jokulsa à Bru) since 5 Ma, attesting the intermittent development of a small ice cap in place of the southern (and highest) portion of the Vatnajökull. Island-wide glaciations spread from the Plio-Pleistocene transition with glacial-interglacial cyclicity indicated from ~2.6 Ma, followed by step-like amplifications at 2.2-2.1, 1.6 Ma and after 1 Ma.
The sedimentary sequence of Tjorness Group records continuously the crucial period between 4 and 2.5 Ma. Cooling and glacio-marine tillites are interbedded in the youngest *Serripes* serie, although the two older members are still temperate. The next fossiliferous group, the Furuvik Group, c.2.2 Ma, contents evidence of two major tillites, marking the onset of a real ice.sheet reaching the coast. The

next group, the Breidavik one (2.0-1.2 Ma), contents 6 tillite beds. Almost 20 glaciations are recorded in Iceland (fig.1).

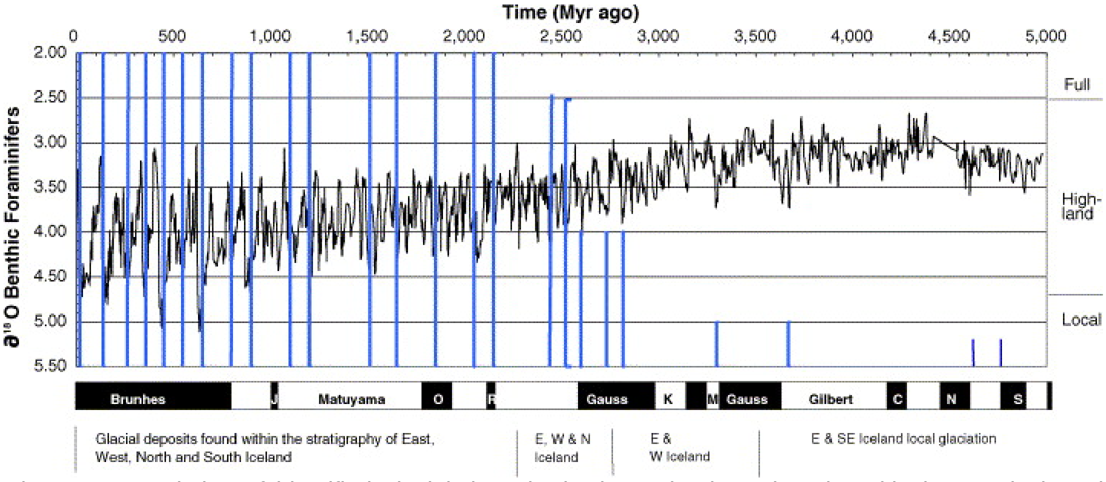

Figure 1: Correlation of identified glacial deposits in the Iceland stratigraphy with the Tropical Pacific benthic isotope record from core ODP849 for 0–5 Ma. Lines show the approximate position of glacial deposits found in the Icelandic stratigraphy. (Geirsdottir et al. 2007)

The Middle Pleistocene transition (MPT).

Evidences of large glaciations exist thus from 1.2 Ma. At the North edge of Skagi peninsula, glacio-marine sediments sealed by basalts yield this date. Huge volcanism existed in the rift from 1.2 to 1 Ma inland and along the Snaefelness ridge. At that time also the first móbergs (subglacial table volcanoes) are observed in Skjalfandi (Littla Saltvik), truncated by temperate based glaciers.

From an oceanic point of view, the Middle Pleistocene Transition can be divided into a first transition (1000 - 920 ka), the MPT s.s. (920 - 640 ka) and a second transition (640 - 530 ka; Schmieder et al., 2000). In the NE of Iceland, most hyaloclastite ridges formed during large glaciation formed from 1 Ma and mostly close to 750-700 ka. Glacial permanence of the Vatnajökull is indicated since only 790 ka (Helgason & Duncan, 2001).

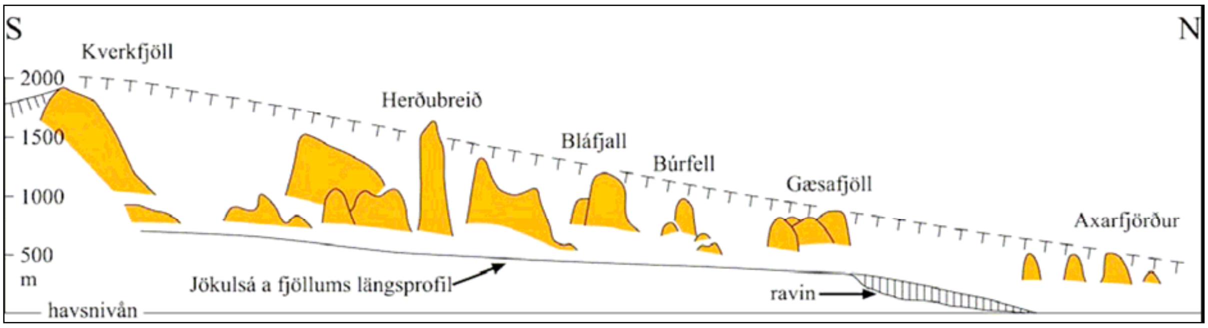

Fig.2 Altitude of the móbergs (transect Vatnajökull to Oxarfjodur) and the volume of the Icelandic ice sheet (Walker 1965). All these móbergs are supposed to belong to the Last glaciation.

After the onset of the MPT event, a main effusive event occurred from 750 to 700 ka in the NE of Iceland, damming the glacially shaped Jökudalur in the middle of the Jökuldalheidi allowing the formation of a hudge paleolake, the Múlalón (Guillou et al., 2009), recorded by 80 m of thick sandy glaciolacustrine deposits, the Laugarvalla sediments. Laugarvalla serie A, below the lower basalt (750 ka) corresponds to MIS 19 deglaciation, and the basal hyaloclastite probably traces MIS 22 (~920-880 ka), an important glaciation responsible for a basal nonconformity that marks the onset of very large glaciations, The main deposits, Laugarvalla B sediments, younger than 750 ka and including two glacial events correspond fairly well to the twinned stadial of MIS 18. Laugarvalla C, deposited during the onset of the major MIS 16 glaciation, also responsible for a major erosionnal discontinuity. After the complete levelling of the landscape by the MIS 16 glaciation, the overflowing by interglacial basalts was extensive from MIS 15 to MIS 13 (560-480 ka). Similar deposits exist in the East : the age of the lacustrine deposits of the Sinafellsfjall is though to yield c.700 ka.

This period is mild and characterised by limited glaciations (Lisiecki and Raymo, 2005).

The MIS 12.

The intensification in glacial conditions is indicated offshore by a marked increase in the accumulation rates of IRD in the Northern Atlantic during MIS 16 and 12 (Helmke et al., 2005; Hoddel et al., 2008) and by a weakening of the THC (Hoddel et al., 2008). The largest glacial extent in Iceland seems to occur during this MIS 12 glaciation (430 ka) with móberg formation on Snaefellness and very large móbergs inland as the Laufafell (south) or the Hagónga, south of the Hofsjökull (Guillou et al, 2009). During the last 500 kyr, rates of erosion increased to 50–175 cm kyr^{-1} (Geirsdottir et al., 2007). The ice sheet reaches the platform edge in SE Iceland (V.Bout Roumazeille, pers.com.).

The Saalian (MIS 8 & 6)

Saalian I (MIS 8 (280-240 ka) is not a major glaciation following the δ18 O isotopic curve of Liesencki & Raymo (2005). Nevertheless, major mobergs formed close to 250 ka, especially the eastern Snaefell (Guillou et al, 2009). Hyaloclastite ridge activity persisted under large ice sheets. MIS 7 is a cool complex interglacial, but no clear evidence of it is observed in Iceland. Some ice sheets are preserved at that time on Scandinavia.

Saalian II (MIS 6, 180-135 ka), was characterised by a major, temperate-base ice mass (Van Vliet-Lanoë et al., 2005) that probably covered most of the shelf. MIS 6 is associated with the storage of huge amounts of ice on land masses around the North Atlantic (Ehlers, 1983; Mangerud et al., 1998; Svendsen et al., 2004), due to the mild conditions in the Atlantic Ocean (Funnell, 1995). In Iceland this explains the erosional capability of the ice masses which mostly shaped the present-day morphology. The MIS 6 ice sheet was thick and extensive, and associated with ice-streams and major glacio-isostatic rebound in southern Iceland. Major subglacial activity occurred close to prior 150 ka, even in Eyafjordur (Guillou et al, 2009). Nevertheless, some deglaciation probably developed close to 150 ka a shown by subaerial lava flows. The glacial load on Iceland at the end of MIS 6 also explains the importance of the subglacial hyaloclastites, which were further reworked by Termination II.

The Last Interglacial and Termination II

Important lava flows and phreatomagmatism occurred during Termination II in the North Volcanic Zone as well as on Snaefelness, sealed by interglacial deposits. Also the Hekla volcano seems to be very early active, perhaps explaining the basaltic tephra described by Wastegard et al, 2005 at 132 ka in the Faeroe Island. Jökulhaups are common during deglaciation both in the North and the South . The sedimentary record of this period is widely spread in the North Volcanic zone, in the Vopnafjördur valley, in the upper Jökuldalur, in the Ranga valley (in the South), and east of Snaefellness, on the strandflat. This interglacial was one of the possible interpretations of the Fossvögur formation but also for the Ellivögur one (close to Reykjavik). First described in the North (van Vliet-Lanoë et al, 2005) it will be described now as the Ranga formation. The deposits formed during MIS 6 deglaciation and MIS 5e mainly derive hyaloclastitic sands. It records one lateglacial re-advance (Zeifen-Kategat oscillation), two climate optima with coastal highstands, interglacial paleosols interrupted by two successive glacial advances were correlated with the Middle Eemian cooling (Van Vliet-Lanoë et al, 2007). Permafrost certainly extended in altitude from the mid Eemian cooling.

The Weichselian

The precise timing of the Last Glacial Maximum (LGM) and the full extent of the Iceland ice sheet is poorly constrained, although the deglacial cycle is reasonably well defined. In Iceland, several authors have postulated the existence of a glacial extent that reached the outer border of the island platform or shelf during the Weichselian (e.g., Norðdalh and Halfidason, 1992; Ingólfsson et al., 1997). Móberg's data are also used to indicate the thickness of the ice sheet and to map the boundary of the ice during the Last Glacial Maximum (LGM) (fig.2 , Walker, 1965). Small ice-free (nunataks) areas may have existed along the coastal mountains, particularly in the northwest, north and east during the LGM. Accumulating data indicate that during its maximal extent, weichselian ice streams and outlet glaciers from ice divides in central Iceland terminated at or close to the shelf edge. Several datation show the existence of retracted ice sheet during 5a (aerial lava flow in Skardsengi at 80 ka BP K-Ar), limited deglaciation at 55-60 ka (Thorsmork ignimbrite, Lacasse et al., 2001; rockglaciers at the coast: A.Gudmunsson, 2000) maximum ice load and móberg formation close to 50-40 ka BP (Levi et al., 1991, Guillou et al , 2009). The age of the Latra moraine close to the western shelf edge somewhat older than 36 ka (Syvitski et al, 1999) seems to confirm this. An important retreat from 26 ka in the N & NE of Iceland, younger readvances close to 15 and 13 ka (Van Vliet-Lanoë et al, 2007). The northwestern peninsula seems to have supported an independent ice cap with valley glaciers with outlet glaciers originating within an ice-divide near the centre of the peninsula Principato et al., 2006). This is consistent with the absence of deposits from 26 ka to 17 ka ago offshore of Ejafjordur (North), mentioned by Andrews et al. (2000, 2003), and with the Middle Weichselian transgression reconstructed by Svendsen et al. (2004) for the Scandinavian Arctic. A limited LGM glaciation could also explain the characteristics of the Termination I-a sediments, which are poor in hyaloclastites.

The deglaciation: Termination Ia (Bölling) versus Termination Ib (Younger Dryas)

Classical literature describes deglaciation, with the ice retreating from the present-day coast line during the Younger Dryas or even the Preboreal (Norðdahl and Halfidason, 1992; Ingólfsson et al., 1997),. The classical Vedde Ash (11.8 cal ka BP) and the Saksunarvatn tephra (10.2 cal. ka BP) trace the termination Ib. (Grönvold et al., 1995). A shard like rhyolithic tephra (Skógar) found in secondary position at coastal sites, mostly in the North of the island where it has been correlated with the Vedde Ash, (Norðdahl and Halfidason, 1992): it is commonly used to date Termination Ib (Rundgren et al., 1997). The Vedde ash is a pellet-like marker tephra layer from the Katla Volcano, South Iceland, well known in marine sequences; it has been found on the top of the Mykjuness moraine close to Hella (+90m) and on the marine terrace at +15m in the North (Kaupangur, Eyafjordur) where it postdates clearly the Skógar (13 cal ka). In fact, 3 tephra with similar signature as the Vedde Ash exist. Correlated with an ignimbrite of the Katla (Solheimar ; Lacasse et al., 2001), the Skógar tephra seems older than the maximum deglaciation flooding surface and can be correlated with the Middle Vedde ash c.13.5 cal ka (IA2: in Mortensen et al., 2005; Van Vliet-Lanoë et al, 2007)

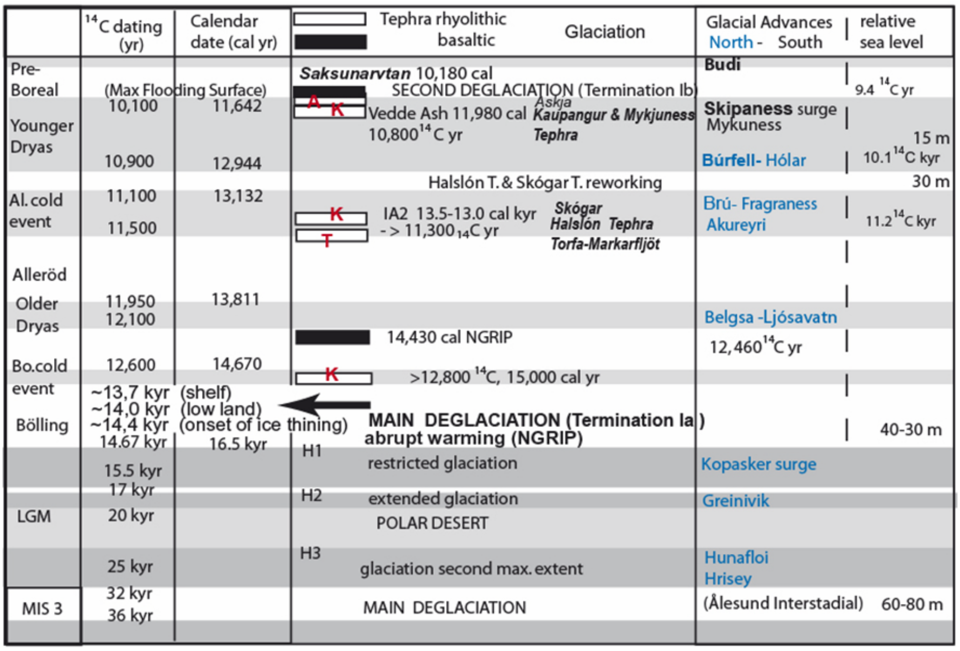

Figure 3; stratigraphical position of the main tephra markers and proposed glacial history of the Weichselian in Northern Iceland (completed from Van Vliet-Lanoë et al., 2007). Skipaness advance occurred c.11600 cal yr; Mykjunes one is slightly older.

The deposits of the Weichselian deglaciation (Termination I *sensu lato*) are much more limited in thickness that for the Termination II. Both in south and northern Iceland considerable deglaciation (Termination I-a) develop from the Bølling onward (cf. Geirsdóttir et al., 1997; Principato et al., 2006; Jennings et al., 2007; Licciardi et al., 2007). Deglaciation seems major as the Skógar tephra is found at the end of the Halslón sedimentation, prior to the Saksunarvatn tephra, 20 km North only of the Vatnajökull (Van Vliet-Lanoe et al., 2007). The occurrence of the Vedde Ash in lake sediment, shows that during the Younger Dryas (12.7–11.5 cal ka) outlet glaciers from a southern Icelandic already retracted icecap, surged locally to the current coastline. It is the case at Borgarfjôrdur where it calved on the strandflat and surged to Skypaness (Hvalfjördur). Deglaciation definitively proceeded from 10.299 cal yr, in the SW of Thingvellir (Mykjunes moraines) or in the North Western peninsula. In northern Iceland, the YD glaciers did not reached the coast but remained already inland as in Eyjafjörður or Oxarfjordür, as shown by the limited importance of the glacial rebound in the North, reinterpreted from the Rundgren et al., 1997 data or by the Kaupangur section (Ejafjördur) . In the North, glaciers were starved in precipitation by a re-extent of the sea-ice and a retracted Irminger current. A limited glacier advance in Southern Iceland occurred during the early Preboreal time from 11.5 to 10.1 cal ka, when the Búði moraines were formed, after the maximum flooding related to glacio-isotsatic rebound. In conclusion, Iceland record an early maximum ice extent during the Weichselian (MIS3), a limited glaciation during the LGM and a major deglaciation in NE Iceland from the Bølling onward are major differences from the interpretations presented in previous works about Iceland .

References

Bleil, U., 1989. Magnetostratigraphy of Neogene and Quaternary sediment series from the Norwegian Sea, Ocean Drilling Program , Leg 104, *Proc.ODP Sci.Res.* 104: 289-901

Einarsson and Albertsson, 1988 T. Einarsson and K.J. Albertsson, The glacial history in Iceland during the past three million years, Philos. Trans. R. Soc. Lond. *B* **318** (1988), pp. 637–644.

Funnell, B.M., 1995. Global sea-level and the (pen)insularity of late Cenozoic Britain. In: Preece, R.C. (Ed.), Island Britain: a Quaternary perspective. Geol. Soc., London, Spec. Publ. 96, 3-13.

Geirsdóttir, A., Miller, G.H. and Andrews, J.T., 2007. Glaciation, erosion, and landscape evolution of Iceland. J.Geodyn. 43 , 170 -186.

Geirsdóttir, Á. 2004. Extent and chronology of Glaciations in Iceland. In Ehlers, J. and Gibbard, P. eds., Quaternary Glaciations — Extent and Chronology of Glaciations. Part 1 Europe. INQUA Commission on Glaciation. Elsevier B.V. 175-182.

Geirsdóttir A., J. Hardardóttir and A.E. Sveinbjörnsdóttir, 2000 Glacial extent and catastrophic meltwater events during the deglaciation of Southern Iceland, Quat. Sci. Rev. **19** , 1749–1761

Geirsdóttir A., J. Hardardóttir and J. Eiriksson, 1997 Depositional history of the Younger Dryas(?)—Preboreal sediments, South Central Iceland, *Arct. Alp. Res.* **29**, 13–23.

Geirsdottir, A . and Eirıksson, J., 1994. Growth of an intermittent ice sheet in Iceland during the late Pliocene and early Pleistocene. Quat.Res., 42, 115 -130.

Guillou H., Van Vliet-Lanoë-B., Guðmundsson A. and S.Nomade. Climate-related Quaternary volcanic activity in Iceland? Insights from new unspiked K-Ar ages. Quaternary Geochronology, 5, 10-19.

Grönvold K., N. Oskarsson, S.J. Johnsen, H.B. Clausen, C.U. Hammer, G. Bond and E. Bard, 1995Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments, *Earth Planet. Sci. Lett.* **135** (1995), pp. 149–155.

Guðmundsson, A., 2000. The relict periglacial face of the Héradsfloí area-East Iceland. [In:] Russel, A. & Marren, P. (Eds): Iceland 2000 - modern processes and past environments. *Keele University, Department of Geography Occasional Papers Series* 21, 44-47.

Haug G.H., Ganopolski A., Sigman D. M., Rosell-Mele A., Swann G. E. A., Tiedemann R.,. Jaccard S. L, Bollmann J.,. Maslin5 M.A, Leng M. J. & Eglinton G. 2005 North Pacific seasonality and the glaciation of North America 2.7 million years ago. Nature 433, 821 -825.

Helgason, J., Duncan, R.A., 2003. Ekkra Geological Consulting, Ar-Ar age dating of the Kárahnjúkar volcanic formation, Kárahnjúkar. Hydroelectric Project, Age dating performed by dr. Robert A. Duncan, Jarðfræðistofan, EKKRA Rept. LV-2003/090, Unpublished Report 39 pp.

Helmke J. P., Bauch H. A., Röhl U., Mazaud A. 2005. Changes in sedimentation patterns of the Nordic seas region across the mid-Pleistocene. Marine Geol., 215, 107-122.

Hodell, D. A., Channell, J. E. T., Curtis, J. H., Romero, O. E., and Röhl, U. ,2008. Onset of “Hudson Strait” Heinrich events in the eastern North Atlantic at the end of the middle Pleistocene transition (~640 ka)? Paleoceanography, 23, PA4218, doi:10.1029/2008PA001591.

Ingólfsson Ó, Björck S., Haflidason H., Rundgren M.1997. Glacial and climatic events in iceland reflecting regional north atlantic climatic shifts during the Pleistocene-Holocene transition. 16, 1135-1144

Knies, J., Matthisen, Vogt, Laberg, J.S., Hjelstuen, B.O., Larsen, E., Andreassen, K., Eidvin, T., Vorren, T.O., 2009. A new Plio-Pleistocene ice sheet model for the Svalbard-Barents Sea region. Quat. Sc. Rev, 28, 812-828.

Lacasse C., Garbe-Schönberg C.D. 2001, Explosive silicic volcanism in Iceland and the Jan Mayen area during the last 6 Ma: sources and timing of major eruptions J.Volc.Geoth.Res., 107, 113-147.

Larsen H. C, A. D. Saunders, P. D. Clift, J. Begét, W. Wei, S. Spezzaferri, J. Ali, H. Cambray, A. Demant, G. Fitton, M. S. Fram, K. Fukuma, J. Gieskes, M. A. Holmes, J. Hunt, C. Lacasse, L. M. Larsen, H. Lykke-Andersen, A. Meltser, M. L. Morrison, N. Nemoto, N. Okay, S. Saito, C. Sinton, R. Stax, T. L. Vallier, D. Vandamme, and R. Werner (The ODP Leg 152 Scientific Party) 1994 Seven Million Years of Glaciation in Greenland. *Science*, , 264, ,952-955.

Levi, S., Audunsson, H., Duncan, R. A., Kristjansson, L., Gillot, P.Y., Jakobsson, S.P. 1990. Late Pleistocene geomagnetic excursion in Icelandic lavas: confirmation of the Laschamp excursion. Earth Plan..Sc. Lett., 96, 443-457.

Licciardi, J.M., Kurz, M.D., Curtice, J.M., 2007. Glacial and volcanic history of Icelandic table mountains from cosmogenic ^{3}He exposure ages: Quat. Sc. Rev. 26, 1529-1546.

Lisiecki, L. E., and M. E. Raymo, 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic δ^{18}O records. Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071.

NGRIP North Greenland Ice Core Project members. 2004. High-resolution record of Northern Hemisphere climate extending into the last interglacial period. Nature, 431, 7005, 147-151.

Norðdahl H., Halfidason H., 1992. The Skógar tephra, a YD marker in North Iceland. Boreas, 21, 23-41.

Syvitski, J.P.M., Jennings, A., and Andrews, J.T., 1999, High-resolution seismic evidence for multiple glaciations across the southwest Iceland Shelf. Arctic, Antarctic and Alpine Research, 31: 50-57.

Van Vliet-Lanoë, B., Bourgeois, O., Dauteuil, O. Embry, J.C, Schneider, J.L., Guillou, H., 2005. Deglaciation and volcano-seismic activity in Northern Iceland: Holocene and Early Eemian. Geodyn. Acta 18, 81-100.

Van Vliet-Lanoë, B., Guðmundsson, A., Guillou, H., Duncan, R.A., Genty, D., Gassem, B., Gouy, S., Récourt, P., Scaillet, S., 2007 Limited glaciation and very early deglaciation in central Iceland: Implications for climate change. CRAS Géosciences 339, 1-12.